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AN ANALYSIS OF MODE-I FRACTURE IN CARBON-EPOXY LAMINATE FOR THE PREDICTION OF CRITICAL LOADS AND CRACK LENGTHS

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ABSTRACT

Present work deals with the analysis of a four layered symmetric angle-ply CFRP laminate for the prediction of critical load for an existing crack and critical crack length at an existing load that causes mode-I fracture in laminate. The problem is simulated in finite element software ANSYS. Virtual crack closure technique (VCCT) is used to estimate the strain energy release rate (SERR). The effect of fiber orientation and crack length on SERR and condition of the laminate are studied.

KEYWORDS: FRP, SERR, VCCT, FEM & Delamination

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Original Article

INTRODUCTION

Interlaminar delamination is one of the modes of failure in FRP composite structures. Conventional stress analysis cannot predict the possibility of crack propagation and failure of the laminate as there is no involvement of the crack length parameter in this analysis. Such problems can be analyzed by fracture mechanics. SERR is one of the fracture parameters and can be conveniently used to analyze composite structures through VCCT and FEM. Choi et al [1] studied the delamination effect in FRP laminates under different load cases and observed that interlaminar fracture energy is significantly more in multidirectional laminates than that for the corresponding unidirectional laminates. Mohamed Rehan et al [2] assessed the effect of ply orientation on fracture behaviour of multidirectional laminates by Double Cantilever Beam(DCB) test and observed that the ply orientation at the crack interface influences the $G_{IC.}$ Rebiere and Gamby [3] suggested an energy criterion to study the damage evolution in a composite cross-ply laminate. Chakraborty and Pradhan [4] studied the effect of ply thickness, fiber orientation and resin stiffness on $G_c$in FRP laminates with delamination at the interface of broken and continuous plies. Chakraborty and Pradhan [5] studied the delamination growth behaviour of FRP composite laminates having two embedded delaminations at the interface under uniaxial and transverse loadings. Wang and Crossman[6] investigated the basic fracture mechanisms involved in matrix-dominated failures in fibrous composite laminates. Young and Hee [7] conducted experiments to characterize the delamination of unidirectional graphite/epoxy composites for different loads causing mode I, mode II and mixed mode fracture. Marom et al [8] investigatedMode I and Mode II delamination fractures in Glass, Carbon and Kevlar fabric reinforced composites and studied the effects of the angle of reinforcement and the fiber volume content. Kranthi and Pranoy [9]investigated the fracture behaviour of four-layered cross-ply laminates with interlaminar delamination by using VCCT. Allix and Corigliano [10] compared numerical simulation and experimental results for the damage analysis due to interlaminar fracture. Srinivasa Rao et al [11] suggested the minimum length required in FE model to study the interlaminar fracture

behaviour of an infinitely wide angle-ply laminate. The present analysis is aimed to evaluate the mode-I critical load to initiate crack propagation at an existing delamination in a symmetric angle-ply laminate using VCCT and FEM. The Analysis is extended to evaluate critical crack length for an applied load.

PROBLEM MODELLING

The laminate dimensions are taken as 100 mm length, 2.5 mm total thickness and the width as sufficiently long (300 mm) to simulate infinite length [11]. Uniform thickness of each layer is taken as 2.5 mm. Delamination length of 45 mm is taken at the central interface at one end of the laminate to evaluate the critical load. An edge line load of 10 N/mm as shown in Figure 1 is considered for predicting the critical crack length. Finite element mesh is generated using a linear brick element SOLID 45 of ANSYS software[12]. This element is suitable for modelling orthotropic materials and each node of this element consists of three degrees of freedom. The model is simply supported along the width of the laminates. The material properties of HTA/6376C carbon/epoxy prepreg composite are taken as [11]; E_1= 120GPa, E_2=10.5GPa, E_3=10.5GPa, ν_{12}= ν_{13}= 0.3, ν_{23}=0.51, G_{12}=G_{13}=5.25GPa, G_{23}=3.48GPa, G_{IC} =260 J/m^2

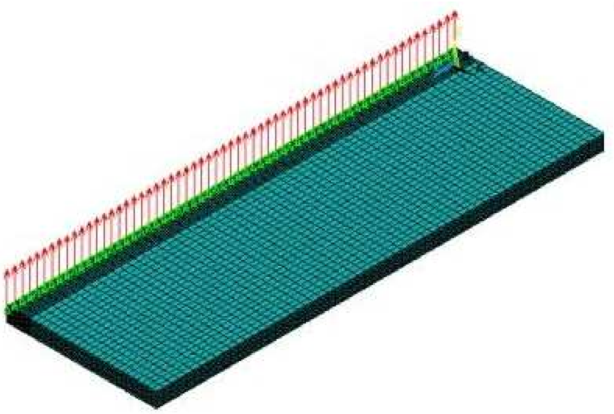

Figure 1: Finite Element Model with Edge Line Loading

RESULTS AND DISCUSSIONS

Initially SERR i. e. G_I is evaluated for an applied line load of 10N/mm for a given crack length of 45 mm. Using the linear relation between the strain energy release rates 'G_I' and square of the load applied 'P^2', SERR is obtained for different loads and the variation of SERR with respect to square of the load is plotted in Figure 2 for different fibre angle orientations.

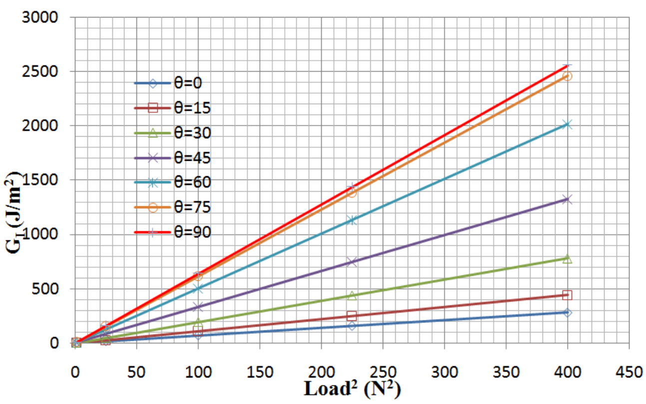

Figure 2: Plot of G_I vs Load^2 for Various values of θ (a= 45mm)

From the graphs drawn between 'G_I' and 'P^2', the critical loads corresponding to G_{IC}=260 J/m^2 are determined for all fiber angles considered. Figure 3 shows one of such plots drawn for $\theta=0^0$. The critical loads obtained in this way for each fibre angle are shown in the Figure 4. It is observed that the critical loads are decreasing with increase in fibre angle.

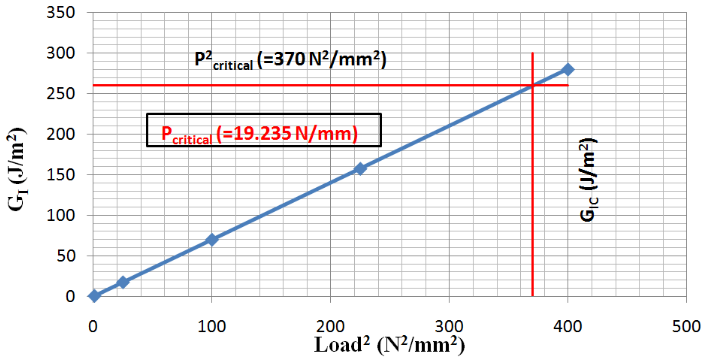

Figure 3: Plot of G_I vs Load^2 for $\theta=0^0$(a= 45mm)

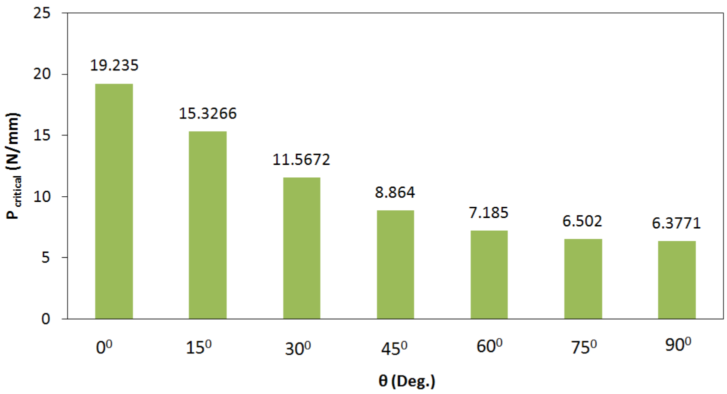

Figure 4: Variation of Critical load with Respect to θ (a= 45mm)

To study the effect of crack length on SERR, separate FE models are considered for each crack length. SERR thus obtained for all considered fibre angle orientations is plotted against crack length in Figure 5. From the graphs drawn between 'G_I' and crack length, the critical loads corresponding to G_{IC}=260 J/m^2 are determined for all fiber angles considered. Figure 6 shows one of such plots drawn for $\theta=15^0$. The critical loads obtained in this way for each fibre angle are shown in the Figure 7. It is observed that the critical crack length is decreasing with increase in fibre angle.

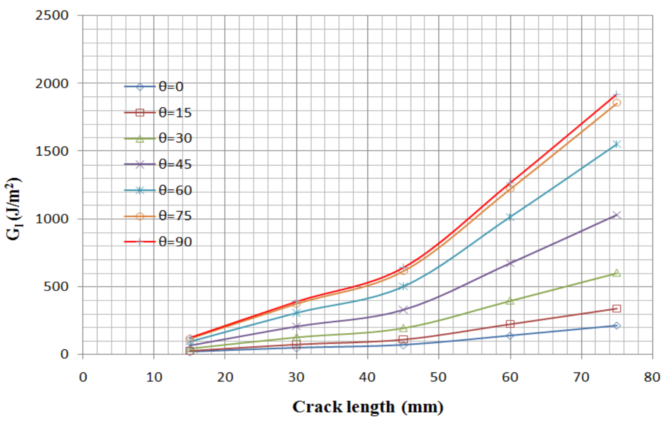

Figure 5: Plot of G_I vs Crack Length for $\theta=0^0$(P= 10 N/mm)

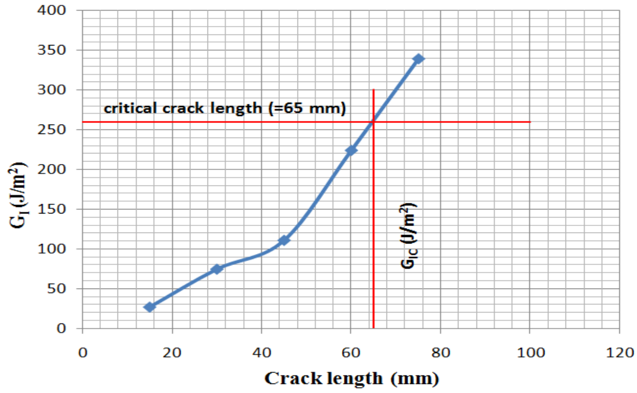

Figure 6: Plot of G_I vs Crack Length for $\theta=15^0$(P= 10 N/mm)

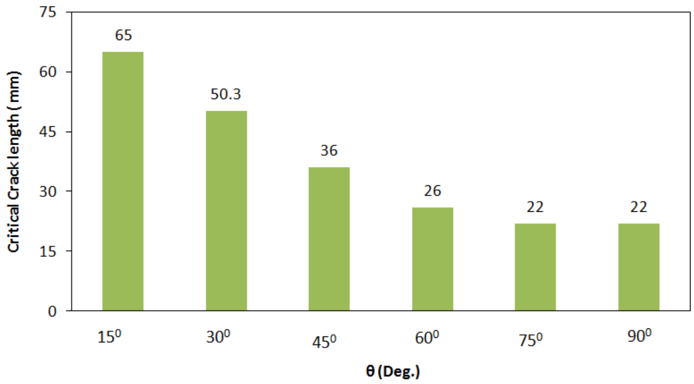

Figure 7: Variation of Critical Crack Length with respect to θ (P= 10 N/mm)

CONCLUSIONS

An attempt has been made to predict the maximum load carrying capacity of a four layered symmetric angle-ply laminate without propagation of existing delamination at the central interface. Allowable crack length at a given load is also predicted. The problem is simulated in finite element analysis software ANSYS and the SERR values are determined using VCCT. It is observed that both the critical load at given crack length and critical crack length at given load are decreasing with the increase in fibre angle orientation.

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